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Modification of jet shapes in PbPb collisions at $\sqrt{s_{NN}} = 2.76$ TeV

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The first measurement of jet shapes, defined as the fractional transverse momentum radial distribution, for inclusive jets produced in heavy-ion collisions is presented. Data samples of PbPb and pp collisions, corresponding to integrated luminosities of 150 μb^{-1} and 5.3 pb^{-1} respectively, were collected at a nucleon–nucleon centre-of-mass energy of $\sqrt{s_{NN}} = 2.76$ TeV with the CMS detector at the LHC. The jets are reconstructed with the anti-k_T algorithm with a distance parameter $R = 0.3$, and the jet shapes are measured for charged particles with transverse momentum $p_T > 1$ GeV/c. The jet shapes measured in PbPb collisions in different collision centralities are compared to reference distributions based on the pp data. A centrality-dependent modification of the jet shapes is observed in the more central PbPb collisions, indicating a redistribution of the energy inside the jet cone. This measurement provides information about the parton shower mechanism in the hot and dense medium produced in heavy-ion collisions.

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1. Introduction

High transverse momentum partons produced in heavy-ion collisions are expected to lose energy while traversing the hot and dense medium created in these collisions [1,2]. This phenomenon, known as "jet quenching", was discovered at the Relativistic Heavy Ion Collider (RHIC) [3–5] through the observation of a suppressed production of high transverse momentum (p_T) particles, and a modification of back-to-back dihadron yields [6,7]. These findings contributed to the conclusion that a strongly coupled quark–gluon plasma (sQGP) is being produced in nucleus–nucleus collisions at RHIC [8–11]. The characterization of the properties of the sQGP and their evolution with centre-of-mass energy is a central goal of the heavy-ion experimental programs at RHIC and at the Large Hadron Collider (LHC). Despite the extensive set of RHIC measurements (see e.g. [12] for a review) utilizing high p_T particles that are presumed to be the leading fragments of jets, the jet-medium interactions are not yet completely understood and theoretical descriptions yield significant qualitative differences in the extracted medium properties [13–15].

Measurements involving a full set of jet observables provide more stringent constraints [16,17]. With the order of magnitude increase in the centre-of-mass energy compared to RHIC, jets with energies well above the background from the underlying event are observed at the LHC. This has allowed the study of jet quenching with high p_T particles [18,19], inclusive jets [20,21] and jet coincidence measurements [21–24].

Jet quenching studies have been performed as a function of the collision centrality, defined as a fraction of the total inelastic nucleus–nucleus cross section, with 0% denoting the most central collisions (impact parameter $b = 0$) and 100% denoting the most peripheral collisions. A strong increase in the fraction of jet pairs with largely unbalanced transverse momentum has been observed in central PbPb collisions compared to peripheral collisions and to unquenched Monte-Carlo models [22,24]. The missing jet energy was found to be carried by soft particles that are well separated in direction from the axis of the back-to-back jets [22]. The fragmentation patterns of the jet constituents were found to be consistent with the fragmentation in pp collisions at the same nucleon–nucleon centre-of-mass energy [25] when only high p_T hadrons (>4 GeV/c) are considered. To further elucidate the multi-gluon emission process and the in-medium shower development [26–32], we study the inclusive jet transverse-momentum profiles (shapes) in PbPb collisions of different centralities including low-p_T particles (>1 GeV/c), and perform a direct comparison with the jet shapes measured in pp collisions. The jet shapes describe how the jet transverse momentum is distributed as a function of the radial distance from the jet axis and are expected to contain important information on the energy loss mechanism due to the medium interactions [33–35]. These studies complement the previous measurements [22] in which jet-track correlations were studied in several bins of dijet asymmetry.

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Jet shape measurements are challenging due to the difficulties in discriminating hadrons originating in the parton shower from those produced by the thermally equilibrated medium or through soft processes in the underlying event. Furthermore, the lost energy may result in softer hadrons that appear in the tail of the jet energy distribution and require large statistics for any modification of the jet shapes to be measured reliably. During the 2011 heavy-ion data-taking at the LHC, the Compact Muon Solenoid (CMS) experiment recorded PbPb collisions at a nucleon–nucleon centre-of-mass energy of $\sqrt{s_{NN}} = 2.76$ TeV. The integrated luminosity of 150 μb^{-1} for the collected sample is sufficient to allow the first measurement of jet shapes in heavy-ion collisions. A reference measurement in pp collisions at the same centre-of-mass energy has been performed using the data sample from 2013. The pp integrated luminosity of 5.3 pb^{-1} yields a kinematic reach for the jets similar to that in the PbPb data. The modification of the jet shapes in the PbPb collisions is studied in five classes of collision centrality: 0–10%, 10–30%, 30–50%, 50–70% and 70–100%.

2. Experimental setup, triggers, and event selection

The CMS detector [36] features nearly hermetic calorimetric coverage and high-resolution tracking for the reconstruction of energetic jets and charged particles. The calorimeters consist of a lead tungstate crystal electromagnetic calorimeter (ECAL) and a brass-scintillator hadron calorimeter (HCAL) with coverage up to $|\eta| = 3$, where $\eta = -\ln[\tan(\theta/2)]$, and θ is the polar angle relative to the counterclockwise beam direction. The quartz/steel forward hadron calorimeters (HF) extend the calorimetry coverage in the pseudorapidity region of $3 < |\eta| < 5.2$ and are used to determine the centrality of the PbPb collision [37]. The calorimeter cells are grouped in projective towers of granularity $\Delta\eta \times \Delta\phi = 0.087 \times 0.087$ (where ϕ is the azimuthal angle in radians) for the central pseudorapidities used in the jet measurement, and have coarser segmentation (about twice as large) at forward pseudorapidity. The central calorimeters are embedded in a superconducting solenoid with 3.8 T central magnetic field. The jet shape measurements are performed using charged particles that are reconstructed by the CMS tracking system, located inside the calorimeter and the superconducting coil. It consists of silicon pixel and strip layers covering the pseudorapidity range $|\eta| < 2.5$ and provides track reconstruction with momentum resolution of about 1–2% up to $p_T = 100$ GeV/c. A set of scintillator tiles, the beam scintillator counters (BSC), are mounted on the inner side of the HF calorimeters and are used for triggering and beam-halo rejection. The BSCs cover the range $3.23 < |\eta| < 4.65$.

For online event selection, CMS uses a two-level trigger system: a level-1 (L1) and a high-level trigger (HLT). The events selected for this analysis in PbPb collisions are using an inclusive single-jet trigger which requires an L1 jet with $p_T > 52$ GeV/c and an HLT jet with $p_T > 80$ GeV/c, where the jets are reconstructed using the energy deposits in the calorimeters. The jet p_T value is corrected for the p_T-dependent calorimeter energy response using the online implementation of the jet-finding algorithm [38]. For pp collisions, events are selected if they pass an L1 jet trigger threshold of $p_T > 36$ GeV/c and an HLT jet threshold of $p_T > 60$ GeV/c. The jet trigger efficiencies are evaluated using minimum-bias-triggered events that are selected by requiring coincidence signals registered either in the BSCs, or in the HF calorimeters. For jets with $p_T > 100$ GeV/c, both the pp and PbPb jet triggers are found to be fully efficient with respect to the offline jet reconstruction, which uses a different jet algorithm based on the full detector information, as discussed in Section 3.

Offline selections are applied to ensure a pure sample of inelastic hadronic collision events both in the jet-triggered and in minimum-bias-triggered events. These selections remove contamination from non-collision beam backgrounds and from ultraperipheral collisions (UPC) that lead to an electromagnetic breakup of one or both of the Pb nuclei. The beam-halo events are vetoed based on the BSC timing. To remove UPC and beam-gas events, an offline HF coincidence of at least three towers on each side of the interaction point is required, with a total deposited energy of at least 3 GeV in each tower. Events with a reconstructed primary vertex based on at least two tracks with transverse momenta above 75 MeV/c are selected. Rejection of beam-induced background events is based on the compatibility of pixel cluster shapes with the reconstructed primary vertex. Additionally, a small number of events with instrumental noise in the hadron calorimeter are removed. The events are sorted according to their centrality based on the energy deposited in the HF calorimeters. Further details on the triggering and event selections can be found in Ref. [23].

3. Jet and track reconstruction

Monte Carlo (MC) event generators have been used for evaluation of the jet and track reconstruction performance, particularly for determining the tracking efficiency, as well as the jet energy response and resolution. Jet events are generated by the PYTHIA MC generator [39] (version 6.423, tune Z2 [40]). These generated PYTHIA events are propagated through the CMS detector using the GEANT4 package [41] to simulate the detector response. In order to account for the influence of the underlying PbPb events, the PYTHIA events are embedded into fully simulated PbPb events, generated by HYDJET [42] (version 1.8) that is tuned to reproduce the total particle multiplicities, charged-hadron spectra, and elliptic flow at all centralities. The embedding is done by mixing the simulated digital signal information from PYTHIA and HYDJET, hereafter referred to as PYTHIA + HYDJET. These events are then propagated through the standard reconstruction and analysis chains.

For both pp and PbPb collisions, the analysis is based on reconstructed jets using the anti-k_T jet-finding algorithm [43], with a distance parameter $R = 0.3$, utilizing particle-flow (PF) objects that combine information from all CMS detector subsystems [44,45]. The small value of R is used to reduce the effects of fluctuations in the heavy-ion background. In the PbPb data, the underlying event can affect jet-finding and distort the reconstructed jet energy. The background energy is subtracted using an iterative "noise/pedestal" subtraction technique as described in Ref. [46]. The jet-finding efficiency is above 99% for jets with $p_T > 100$ GeV/c and $|\eta| < 2$. The p_T of the reconstructed jets used in the analysis is corrected to the particle-level jet p_T based on the PYTHIA generator level information, where all stable particles ($c\tau > 1$ cm) are included to determine the particle-level jet p_T [38]. The uncertainty on the absolute jet energy scale in pp collisions is about 3% for jet $p_T > 50$ GeV/c with $|\eta| < 3$. In PbPb collisions, due to the influence of the underlying heavy-ion events, this uncertainty increases to about 5%.

Charged particles with transverse momentum $p_T > 1$ GeV/c are used to reconstruct the jet shapes. The track finding algorithms and track selection criteria are similar to the ones used in previous CMS publications [18,25]. The tracks are reconstructed starting from a "seed" comprising three reconstructed signals ("hits") in the silicon pixel detector that are compatible with a helical trajectory with minimum p_T of 0.9 GeV/c originating from a selected region (±1 mm in the transverse direction, and ±2 mm longitudinally) around the reconstructed primary vertex. This seed is then propagated outward through subsequent tracker layers using a combinatorial Kalman-filter algorithm [47]. The PbPb and the pp data are reconstructed using the same procedure. The geometric acceptance and algorithmic efficiencies are not studied separately,

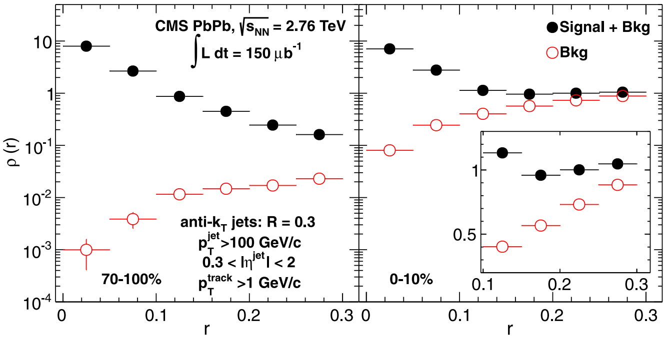

Fig. 1. (Color online.) Differential jet shapes obtained from the jet cone before background subtraction (filled circles), and from the "η-reflected" background cone (open circles), as a function of the distance from the jet axis in two PbPb centrality intervals: 70–100% (left) and 0–10% (right). The measurements use inclusive jets with $p_T^{\text{jet}} > 100$ GeV/c and $0.3 < |\eta| < 2$, and charged particles with $p_T^{\text{track}} > 1$ GeV/c.

but considered together as an absolute efficiency. The track selection criteria are optimized to ensure that the contribution from misidentified tracks and secondary particles is as low as possible in the whole kinematic range for this analysis ($|\eta| < 2.3$), while preserving a reasonable reconstruction efficiency. For the present analysis, the tracking efficiency at $p_T = 1$ GeV/c is 45% in the most central (0–10%) PbPb collisions and 53% in pp collisions. The efficiency increases at higher p_T and is approximately constant above $p_T = 5$ GeV/c, reaching 65% (70%) in PbPb (pp) collisions. The misidentified track and secondary particle contributions are typically below 2% for all the samples used in this analysis, with the exception of particles with $p_T < 2$ GeV/c detected at forward pseudorapidities and in the most central PbPb events, where the misidentified track and secondary particle contributions reach 6% and 3%, respectively. For each centrality class used in the analysis, the charged-particle yields are corrected for efficiency, misidentified track and secondary contributions on a track-by-track basis using a detailed (η, p_T) map determined from PYTHIA events embedded into HYDJET background. A similar efficiency correction has been performed for pp data with the correction factors derived from PYTHIA. In the simulation, the corrected reconstructed track p_T distribution agrees to within 3% with the generator level inclusive charged-particle distribution at any given p_T.

4. Analysis method and systematic uncertainties

The differential jet shape, $\rho(r)$, describes the radial distribution of transverse momentum inside the jet cone:

$$\rho(r) = \frac{1}{\delta r}\frac{1}{N_{\text{jet}}}\sum_{\text{jets}}\frac{\sum_{\text{tracks}\in[r_a,r_b)} p_T^{\text{track}}}{p_T^{\text{jet}}} \tag{1}$$

where the jet cone is divided into six annuli with radial width $\delta r = 0.05$, and each annulus has an inner radius of $r_a = r - \delta r/2$ and outer radius of $r_b = r + \delta r/2$.

Here $r = \sqrt{(\eta_{\text{track}} - \eta_{\text{jet}})^2 + (\phi_{\text{track}} - \phi_{\text{jet}})^2} \leqslant 0.3$ is the reconstructed track's radial distance from the jet axis, defined by the coordinates η_{jet} and ϕ_{jet}. The transverse momenta of the reconstructed track and jet are denoted p_T^{track} and p_T^{jet} respectively. After applying tracking efficiency corrections, the transverse momentum of all charged particles with $p_T > 1$ GeV/c in each annulus is summed to obtain the fraction of the total jet p_T carried by these particles. The results are averaged over the total number of selected jets, N_{jet}.

In heavy-ion collisions, particles from the underlying event that happen to fall inside the jet cone would modify its shape. To compensate, this contribution is subtracted following a procedure previously employed by CMS in the measurement of the jet fragmentation function [25]. To estimate the charged-particle background, a "background cone" is defined by reflecting the original jet axis about $\eta = 0$, while preserving its ϕ coordinate ("η-reflected" method). To avoid overlap between the signal jet region and the background cone, jets with axes in the region $|\eta_{\text{jet}}| < 0.3$ are excluded from the analysis. Larger exclusion regions, up to $|\eta_{\text{jet}}| < 0.8$ have also been studied to investigate possible biases in this procedure due to large-angle correlations between the particles originating from different jets in the event. The size of the exclusion region is not found to be a significant source of systematic uncertainty in the jet-shape measurement.

The charged particles that are found in the background cone are used to evaluate the background jet shape using Eq. (1), which is then subtracted from the reconstructed jet shape that contains both signal and background particles. After background subtraction, the integral of $\rho(r)$ over the range $0 \leqslant r \leqslant R$ is normalized to unity. The normalization factor accounts for the average fraction of the total jet p_T carried by charged particles with $p_T > 1$ GeV/c. The differential jet shapes reconstructed using all charged particles (labeled "Signal + Bkg") and the corresponding background distributions (labeled "Bkg") are shown in Fig. 1 for the most peripheral (70–100%) and the most central (0–10%) collisions. The background is a small fraction of the result ($\leqslant$1%) in the centre of the jet but contributes a larger fraction further away from the jet axis. In peripheral events, the fraction of background at large radii is only about 15%, but it is significantly larger ($\approx$85%) in central events.

The background-subtraction technique is validated using MC simulations. Jets generated with PYTHIA are embedded into heavy-ion underlying events of various centrality classes generated with the HYDJET event generator. The results of the differential jet-shape measurements from embedded events are then compared to those obtained from a PYTHIA jet sample at the generator level, using the same analysis procedure. The ratios of the background-subtracted shapes measured from PYTHIA + HYDJET sample and those measured in the PYTHIA sample are shown in Fig. 2 for the five centrality classes used in the analysis. The agreement is better than 5% even for the most central collisions, where the background is relatively large and its fluctuations become important.

An alternative "event-mixing" technique is used as a cross-check of the background subtraction procedure. Minimum-bias-triggered events are considered to be representative of the background. Each jet-triggered event is randomly matched to ten minimum bias PbPb events that are required to have similar global characteristics: the primary vertices have longitudinal positions within 5 cm, the relative difference in centrality is less than 25%,

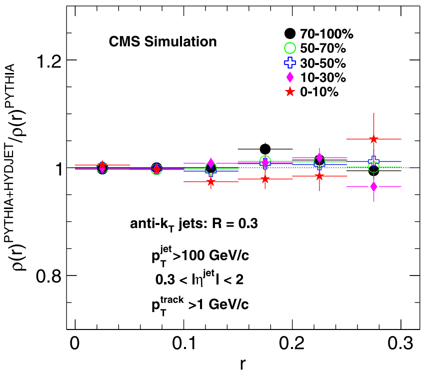

Fig. 2. (Color online.) Ratio of jet shapes for jets generated with PYTHIA and embedded into heavy-ion background events simulated by HYDJET, to those obtained from the PYTHIA signal alone. The analysis uses the same background subtraction procedure ("η-reflected") as in data. The measurements use inclusive jets with $p_T^{jet} > 100$ GeV/c and $0.3 < |\eta| < 2$, and charged particles with $p_T^{track} > 1$ GeV/c.

Table 1

Systematic uncertainties in the measurement of the differential jet shapes in PbPb collisions, and in the ratio to the pp based reference measurement $\rho(r)^{PbPb}/\rho(r)^{pp}$. The uncertainties have a small centrality dependence and the table shows the maximum values that typically correspond to the most central collisions.

Source	Distance from jet axis (radius)			
	$r \leqslant 0.1$		$r \geqslant 0.2$	
	$\rho(r)$	Ratio	$\rho(r)$	Ratio
Background subtr.	2%	2%	10%	10%
Tracking eff.	7%	4%	7%	4%
Jet energy scale & res.	2%	2%	7%	5%
Total	8%	5%	14%	12%

and the event plane angle, as determined from the azimuthal anisotropy of the energy deposited in the HF calorimeters [47], is the same within 250 mrad. Alternate values for these selection requirements are also studied and lead to negligible differences in the analysis results. The particles from these selected minimum bias events are used to evaluate the background jet shapes corresponding to the jets in the signal sample. The differential jet shapes obtained using this alternative background estimation are then compared to those obtained using the η-reflection technique and the ratio of the two results is used to estimate a systematic uncertainty as listed in Table 1.

The goal of the present measurement is to study the modifications of the jet structure due to the presence of a hot and dense medium produced in PbPb collisions. To evaluate these modifications in each centrality interval of the PbPb measurements, a reference differential jet shape distribution is constructed from the pp data, taking into account the differences in the jet energy scale, jet momentum resolution, and the jet p_T distributions in the two systems. These adjustments are needed to ensure that the comparison is free of detector effects and that the kinematic range of the jets included in the comparison is the same. Based on MC studies, the reconstructed p_T of every jet in the pp data has been shifted to remove any residual differences in the jet energy scale between the two systems due to background fluctuations. These shifts are of the order of 1–2%, depending on the centrality. Next, the jet p_T is smeared using a Gaussian distribution with a standard deviation determined by the quadratic difference of the jet energy resolution in PbPb and pp collisions. The smearing factors are derived from MC studies, which show that the jet momentum response has little or no deviation from a Gaussian shape in both collision systems. The resulting jet p_T spectrum is compared to the spectra in PbPb collisions in each centrality class in order to determine a jet p_T-dependent weight. This is applied on a jet-by-jet basis to ensure that the spectra of the jets that are included in the jet shape measurement are identical in the two systems. This is important, since the jet shapes depend on jet p_T. Several parametrizations of the p_T dependence of the resolution and the jet energy scale are used to evaluate the uncertainties in this procedure.

Several sources of systematic uncertainties are considered in the measurement of the jet shapes in PbPb collisions and of their nuclear modification factors, $\rho(r)^{PbPb}/\rho(r)^{pp}$. These sources include the tracking efficiency, the background subtraction method, the jet energy resolution and the jet energy scale. They are evaluated as a function of the jet-track distance r and are summarized in Table 1. Uncertainties are shown for representative radius bins only; they vary smoothly in other radius bins that are not shown. Except for those due to the background subtraction, the systematic uncertainties have little or no centrality dependence. The table shows the maximum values that typically correspond to the most central collisions (0–10%). The uncertainties of the p_T-dependent tracking efficiency and misidentified tracks corrections result in uncertainties in the jet shapes, especially at a large distance from the core of the jet ($r \geqslant 0.2$), where most of the particles have low p_T. These uncertainties are less than 7% in the jet shape profile distribution and 4% in the jet shape ratios, and are independent of the centrality of the collisions. The uncertainties resulting from the background subtraction are evaluated using the relative difference in the jet shape distribution obtained with the two background subtraction procedures described above and from the simulation studies at the generator level. In more central events (0–30%), the background subtraction uncertainty is found to be of the order of 2% at the core of the jet and reaches 10% at large distances from the jet axis, where the background is more significant compared to the signal level. These uncertainties are smaller for the more peripheral events (2% for 50–100% and 5% for 30–50% centrality intervals). The uncertainties in the jet energy scale and resolution also have an impact on the measured shapes, as jets migrating in and out of the selected jet p_T range may have a different shape [48]. In PbPb collisions, the uncertainty from this source is of the order of 7% at a large distance from the jet axis, and independent of the centrality of the collisions. In the jet shape ratios, these uncertainties are smaller and have been evaluated by varying the smearing and shifting parameters used in constructing the pp reference spectrum taking into account the relative uncertainty in the jet energy resolution and scale in the two systems. The systematic uncertainties from different sources are added in quadrature.

5. Results and discussion

The differential jet shapes measured in PbPb collisions and the reference constructed based on measurements from pp data are presented in the top row of Fig. 3 for five centrality classes, varying from most peripheral 70–100% (left) to most central 0–10% (right). In both collision systems, 85% of the transverse momentum is concentrated in the core of the jet at radii $r < 0.1$, and the small amount ($\approx$5%) of p_T contained at radii $r > 0.2$ is carried by low-p_T particles. The largest differences between the jet shapes measured in the PbPb and pp systems are observed at large radii in the most central PbPb collisions. To quantify these modifications, the ratios $\rho(r)^{PbPb}/\rho(r)^{pp}$ are plotted in the bottom row of Fig. 3. Deviations from unity indicate a modification of jet structure in the nuclear medium. Recall that the integrals of the jet shapes are normalized to unity and, as a result, an excess at one distance r from the jet axis has to be compensated by a depletion at another location. In the peripheral collisions (70–100%), the ratio is close to unity within the uncertainties in the whole measured range, which indicates that the radial distribution of the summed transverse momentum of the particles inside the jets is similar in the

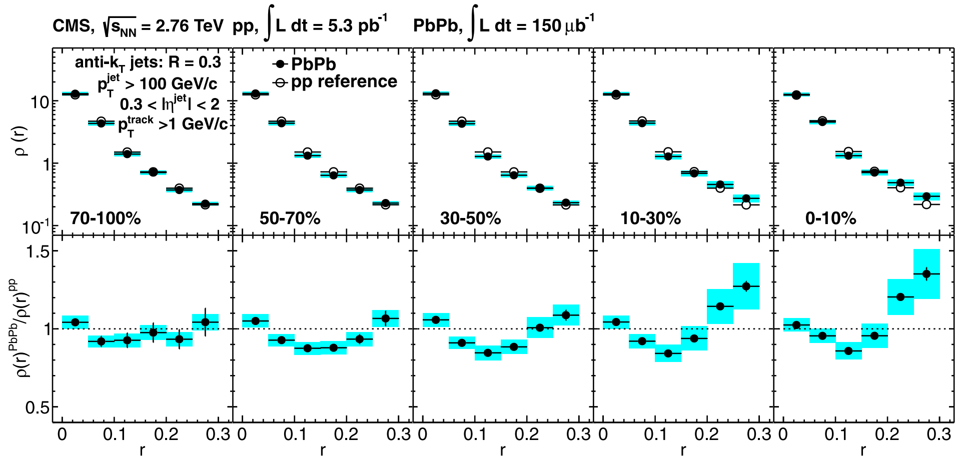

Fig. 3. (Color online.) Top row: Differential jet shapes in PbPb collisions (filled circles) as a function of distance from the jet axis for inclusive jets with $p_T^{jet} > 100$ GeV/c and $0.3 < |\eta| < 2$ in five PbPb centrality intervals. The measurements use charged particles with $p_T^{track} > 1$ GeV/c. The pp-based reference shapes (with centrality-based adjustments as described in the text) are shown with open symbols. Each spectrum is normalized to an integral of unity. The shaded regions represent the systematic uncertainties for the measurement performed in PbPb collisions, with the statistical uncertainties too small to be visible. Bottom row: Jet shape nuclear modification factors, $\rho(r)^{PbPb}/\rho(r)^{pp}$. The error bars show the statistical uncertainties, and the shaded boxes indicate the systematic uncertainties.

two systems. In more central PbPb collisions (0–70%), a depletion is observed in the region $0.1 < r < 0.2$ with a typical value of the ratio $\rho(r)^{PbPb}/\rho(r)^{pp}$ around 0.84 and a total uncertainty of less than 7%. In the most central PbPb collisions (10–30% and 0–10%), an excess of transverse momentum fraction emitted at large radius $r > 0.2$ emerges, indicating a moderate broadening of the jets in the medium. At the largest radius $0.25 < r < 0.3$, the value of the ratio $\rho(r)^{PbPb}/\rho(r)^{pp}$ is 1.04 ± 0.09 (stat.) ± 0.05 (syst.) for the most peripheral collisions (70–100%), while in the central collisions (10–30% and 0–10%) it increases to 1.27 ± 0.03 (stat.) ± 0.15 (syst.) and 1.35 ± 0.05 (stat.) ± 0.16 (syst.), respectively. These observations are consistent with previous studies in CMS which find that the energy that the jets lose in the medium is redistributed at large distances from the jet axis outside the jet cone [22]. The differential study of the jet structure presented here provides important additional information and shows that nuclear modifications are also present inside the jet cone. Qualitatively, a similar trend is predicted by theory [34,35] based on parton level calculations for PbPb collisions at a different centre-of-mass energy. It is expected that a detailed theory-experiment comparison will be performed in the future, in which the theoretical calculations would include all experimental cuts that would influence the observed correlations, and model the effects due to the hadronization process. This comparison will contribute to our understanding of the medium properties.

6. Summary

The first measurement of jet shapes in PbPb collisions at $\sqrt{s_{NN}} = 2.76$ TeV has been performed. The results have been compared to reference shapes measured in pp collisions at the same centre-of-mass energy. Inclusive jets with $p_T^{jet} > 100$ GeV/c and $0.3 < |\eta| < 2$ have been reconstructed using the anti-k_T algorithm with a distance parameter $R = 0.3$, and the jet shapes have been studied using charged particles with $p_T > 1$ GeV/c as a function of collision centrality. In peripheral collisions, the shapes in PbPb are similar to those in the pp reference distributions. A centrality dependent modification of the jet shapes emerges in the more central PbPb collisions. A redistribution of the jet energy inside the cone is found, specifically, a depletion of jet transverse momentum fraction at intermediate radii, $0.1 < r < 0.2$, and an excess at large radii, $r > 0.2$. These results are important for characterizing the shower evolution in the presence of a hot and dense nuclear medium.

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References

[1] J.D. Bjorken, Energy loss of energetic partons in QGP: possible extinction of high p_{T} jets in hadron–hadron collisions, http://lss.fnal.gov/archive/preprint/fermilab-pub-82-059-t.shtml, 1982, FERMILAB-PUB-82-059-THY.

[2] M. Gyulassy, M. Plumer, Jet quenching in dense matter, Phys. Lett. B 243 (1990) 432, http://dx.doi.org/10.1016/0370-2693(90)91409-5.

[3] K. Adcox, et al., PHENIX Collaboration, Suppression of hadrons with large transverse momentum in central Au + Au collisions at $\sqrt{s_{NN}} = 130$ GeV, Phys. Rev. Lett. 88 (2002) 022301, http://dx.doi.org/10.1103/PhysRevLett.88.022301, arXiv:nucl-ex/0109003.

[4] C. Adler, et al., STAR Collaboration, Centrality dependence of high p_{T} hadron suppression in Au + Au collisions at $\sqrt{s_{NN}} = 200$ GeV, Phys. Rev. Lett. 89 (2002) 202301, http://dx.doi.org/10.1103/PhysRevLett.89.202301, arXiv:nucl-ex/0206011.

[5] S.S. Adler, et al., PHENIX Collaboration, Absence of suppression in particle production at large transverse momentum in $\sqrt{s_{NN}} = 200$ GeV d + Au collisions, Phys. Rev. Lett. 91 (2003) 072303, http://dx.doi.org/10.1103/PhysRevLett.91.072303, arXiv:nucl-ex/0306021.

[6] C. Adler, et al., STAR Collaboration, Disappearance of back-to-back high p_{T} hadron correlations in central Au + Au collisions at $\sqrt{s_{NN}} = 200$ GeV, Phys. Rev. Lett. 90 (2003) 082302, http://dx.doi.org/10.1103/PhysRevLett.90.082302, arXiv:nucl-ex/0210033.

[7] J. Adams, et al., STAR Collaboration, Evidence from d + Au measurements for final state suppression of high p_{T} hadrons in Au + Au collisions at RHIC, Phys. Rev. Lett. 91 (2003) 072304, http://dx.doi.org/10.1103/PhysRevLett.91.072304, arXiv:nucl-ex/0306024.

[8] K. Adcox, et al., PHENIX Collaboration, Formation of dense partonic matter in relativistic nucleus–nucleus collisions at RHIC: Experimental evaluation by the PHENIX Collaboration, Nucl. Phys. A 757 (2005) 184, http://dx.doi.org/10.1016/j.nuclphysa.2005.03.086.

[9] J. Adams, et al., STAR Collaboration, Experimental and theoretical challenges in the search for the quark–gluon plasma: The STAR Collaboration's critical assessment of the evidence from RHIC collisions, Nucl. Phys. A 757 (2005) 102, http://dx.doi.org/10.1016/j.nuclphysa.2005.03.085.

[10] B.B. Back, et al., PHOBOS Collaboration, The PHOBOS perspective on discoveries at RHIC, Nucl. Phys. A 757 (2005) 28, http://dx.doi.org/10.1016/j.nuclphysa.2005.03.084.

[11] I. Arsene, et al., BRAHMS Collaboration, Quark–gluon plasma and color glass condensate at RHIC? The Perspective from the BRAHMS experiment, Nucl. Phys. A 757 (2005) 1, http://dx.doi.org/10.1016/j.nuclphysa.2005.02.130, arXiv:nucl-ex/0410020.

[12] D. d'Enterria, Jet Quenching, vol. 23: Relativistic Heavy Ion Physics, Springer Materials – The Landolt-Börnstein Database, Springer-Verlag, 2010, http://dx.doi.org/10.1007/978-3-642-01539-7_16, arXiv:0902.2011.

[13] S.A. Bass, C. Gale, A. Majumder, C. Nonaka, G.-Y. Qin, T. Renk, J. Ruppert, Systematic comparison of jet energy-loss schemes in a realistic hydrodynamic medium, Phys. Rev. C 79 (2009) 024901, http://dx.doi.org/10.1103/PhysRevC.79.024901, arXiv:0808.0908.

[14] T. Renk, Constraining the physics of jet quenching, Phys. Rev. C 85 (2012) 044903, http://dx.doi.org/10.1103/PhysRevC.85.044903, arXiv:1112.2503.

[15] N. Armesto, B. Cole, C. Gale, W.A. Horowitz, P. Jacobs, S. Jeon, M. van Leeuwen, A. Majumder, Comparison of jet quenching formalisms for a quark–gluon plasma "brick", Phys. Rev. C 86 (2012) 064904, http://dx.doi.org/10.1103/PhysRevC.86.064904, arXiv:1106.1106.

[16] A. Majumder, M. Van Leeuwen, The theory and phenomenology of perturbative QCD based jet quenching, Prog. Part. Nucl. Phys. A 66 (2011) 41, http://dx.doi.org/10.1016/j.ppnp.2010.09.001, arXiv:1002.2206.

[17] Y. Mehtar-Tani, J.G. Milhano, K. Tywoniuk, Jet physics in heavy-ion collisions, Int. J. Mod. Phys. A 28 (2013) 1340013, http://dx.doi.org/10.1142/S0217751X13400137, arXiv:1302.2579.

[18] CMS Collaboration, Study of high p_{T} charged particle suppression in PbPb compared to pp collisions at $\sqrt{s_{NN}} = 2.76$ TeV, Eur. Phys. J. C 72 (2012) 1945, http://dx.doi.org/10.1140/epjc/s10052-012-1945-x, arXiv:1202.2554.

[19] ALICE Collaboration, Suppression of charged particle production at large transverse momentum in central Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV, Phys. Lett. B 696 (2011) 30, http://dx.doi.org/10.1016/j.physletb.2010.12.020, arXiv:1012.1004.

[20] ATLAS Collaboration, Measurement of the jet radius and transverse momentum dependence of inclusive jet suppression in lead–lead collisions at $\sqrt{s_{NN}} = 2.76$ TeV with the ATLAS detector, Phys. Lett. B 719 (2013) 220, http://dx.doi.org/10.1016/j.physletb.2013.01.024, arXiv:1208.1967.

[21] CMS Collaboration, Studies of jet quenching using isolated-photon + jet correlations in PbPb and pp collisions at $\sqrt{s_{NN}} = 2.76$ TeV, Phys. Lett. B 18 (2013) 773, http://dx.doi.org/10.1016/j.physletb.2012.11.003, arXiv:1205.0206.

[22] CMS Collaboration, Observation and studies of jet quenching in PbPb collisions at $\sqrt{s_{NN}} = 2.76$ TeV, Phys. Rev. C 84 (2011) 024906, http://dx.doi.org/10.1103/PhysRevC.84.024906, arXiv:1102.1957.

[23] CMS Collaboration, Jet momentum dependence of jet quenching in PbPb collisions at $\sqrt{s_{NN}} = 2.76$ TeV, Phys. Lett. B 712 (2012) 176, http://dx.doi.org/10.1016/j.physletb.2012.04.058, arXiv:1202.5022.

[24] ATLAS Collaboration, Observation of a centrality-dependent dijet asymmetry in lead–lead collisions at $\sqrt{s_{NN}} = 2.76$ TeV with the ATLAS detector at the LHC, Phys. Rev. Lett. 105 (2010) 252303, http://dx.doi.org/10.1103/PhysRevLett.105.252303, arXiv:1011.6182.

[25] CMS Collaboration, Measurement of jet fragmentation into charged particles in pp and PbPb collisions at $\sqrt{s_{NN}} = 2.76$ TeV, J. High Energy Phys. 1210 (2012) 087, http://dx.doi.org/10.1007/JHEP10(2012)087, arXiv:1205.5872.

[26] Y. Mehtar-Tani, C.A. Salgado, K. Tywoniuk, Anti-angular ordering of gluon radiation in QCD media, Phys. Rev. Lett. 106 (2011) 122002, http://dx.doi.org/10.1103/PhysRevLett.106.122002, arXiv:1009.2965.

[27] A. Idilbi, A. Majumder, Extending soft-collinear-effective-theory to describe hard jets in dense QCD media, Phys. Rev. D 80 (2009) 054022, http://dx.doi.org/10.1103/PhysRevD.80.054022, arXiv:0808.1087.

[28] J. Casalderrey-Solana, E. Iancu, Interference effects in medium-induced gluon radiation, J. High Energy Phys. 1108 (2011) 015, http://dx.doi.org/10.1007/JHEP08(2011)015, arXiv:1105.1760.

[29] J. Casalderrey-Solana, J.G. Milhano, U. Wiedemann, Jet quenching via jet collimation, J. Phys. G 38 (2011) 124086, http://dx.doi.org/10.1088/0954-3899/38/12/124086, arXiv:1107.1964.

[30] R.B. Neufeld, I. Vitev, Parton showers as sources of energy–momentum deposition in the QGP and their implication for shockwave formation at RHIC and at the LHC, Phys. Rev. C 86 (2012) 024905, http://dx.doi.org/10.1103/PhysRevC.86.024905, arXiv:1105.2067.

[31] J.-P. Blaizot, F. Dominguez, E. Iancu, Y. Mehtar-Tani, Medium-induced gluon branching, J. High Energy Phys. 1301 (2013) 143, http://dx.doi.org/10.1007/JHEP01(2013)143, arXiv:1209.4585.

[32] M. Fickinger, G. Ovanesyan, I. Vitev, Angular distributions of higher order splitting functions in the vacuum and in dense QCD matter, J. High Energy Phys. 1307 (2013) 059, http://dx.doi.org/10.1007/JHEP07(2013)059, arXiv:1304.3497.

[33] C.A. Salgado, U.A. Wiedemann, Medium modification of jet shapes and jet multiplicities, Phys. Rev. Lett. 93 (2004) 042301, http://dx.doi.org/10.1103/PhysRevLett.93.042301, arXiv:hep-ph/0310079.

[34] I. Vitev, S. Wicks, B.W. Zhang, A theory of jet shapes and cross sections: from hadrons to nuclei, J. High Energy Phys. 0811 (2008) 093, http://dx.doi.org/10.1088/1126-6708/2008/11/093, arXiv:0810.2807.

[35] T. Renk, Medium-modified jet shapes and other jet observables from in-medium parton shower evolution, Phys. Rev. C 80 (2009) 044904, http://dx.doi.org/10.1103/PhysRevC.80.044904, arXiv:0906.3397.

[36] CMS Collaboration, The CMS experiment at the CERN LHC, J. Instrum. 3 (2008) S08004, http://dx.doi.org/10.1088/1748-0221/3/08/S08004.

[37] CMS Collaboration, Dependence on pseudorapidity and centrality of charged hadron production in PbPb collisions at a nucleon–nucleon centre-of-mass energy of 2.76 TeV, J. High Energy Phys. 1108 (2011) 141, http://dx.doi.org/10.1007/JHEP08(2011)141, arXiv:1107.4800.

[38] CMS Collaboration, Determination of jet energy calibration and transverse momentum resolution in CMS, J. Instrum. 6 (2011) P11002, http://dx.doi.org/10.1088/1748-0221/6/11/P11002, arXiv:1107.4277.

[39] T. Sjöstrand, S. Mrenna, P. Skands, PYTHIA 6.4 physics and manual, J. High Energy Phys. 0605 (2006) 026, http://dx.doi.org/10.1088/1126-6708/2006/05/026, arXiv:hep-ph/0603175.

[40] R. Field, Early LHC underlying event data – findings and surprises, arXiv:1010.3558, 2010.

[41] S. Agostinelli, et al., GEANT4 – a simulation toolkit, Nucl. Instrum. Methods Phys. Res., Sect. A, Accel. Spectrom. Detect. Assoc. Equip. 506 (2003) 250, http://dx.doi.org/10.1016/S0168-9002(03)01368-8.

[42] I.P. Lokhtin, A.M. Snigirev, A model of jet quenching in ultrarelativistic heavy ion collisions and high-p_{T} hadron spectra at RHIC, Eur. Phys. J. C 45 (2006) 211, http://dx.doi.org/10.1140/epjc/s2005-02426-3, arXiv:hep-ph/0506189.

[43] M. Cacciari, G.P. Salam, G. Soyez, The anti-k_t jet clustering algorithm, J. High Energy Phys. 0804 (2008) 063, http://dx.doi.org/10.1088/1126-6708/2008/04/063, arXiv:0802.1189.

[44] CMS Collaboration, Particle-flow event reconstruction in CMS and performance for jets, taus, and $E_{\mathrm{T}}^{\mathrm{miss}}$, 2009, CMS Physics Analysis Summary CMS-PAS-PFT-09-001, http://cdsweb.cern.ch/record/1194487.

[45] CMS Collaboration, Commissioning of the particle-flow reconstruction in minimum-bias and jet events from pp collisions at 7 TeV, CMS Physics Analysis

Summary CMS-PAS-PFT-10–002 (2010), http://cdsweb.cern.ch/record/1279341.

[46] O. Kodolova, I. Vardanian, A. Nikitenko, A. Oulianov, The performance of the jet identification and reconstruction in heavy ions collisions with CMS detector, Eur. Phys. J. C 50 (2007) 117, http://dx.doi.org/10.1140/epjc/s10052-007-0223-9.

[47] CMS Collaboration, Measurement of the elliptic anisotropy of charged particles produced in PbPb collisions at nucleon–nucleon center-of-mass energy = 2.76 TeV, Phys. Rev. C 87 (2013) 014902, http://dx.doi.org/10.1103/PhysRevC.87.014902, arXiv:1204.1409.

[48] CMS Collaboration, Shape, transverse size, and charged hadron multiplicity of jets in pp collisions at 7 TeV, J. High Energy Phys. 1206 (2012) 160, http://dx.doi.org/10.1007/JHEP06(2012)160, arXiv:1204.3170.

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